UAV Operations during REU 2018 for Deriving Land and Water Elevations in the Yucatán Peninsula

Thomas J. Pingel

Associate Professor

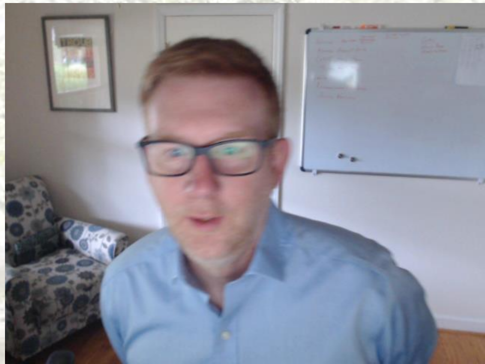
Department of Geography

Virginia Polytechnic Institute and State University

Contact Information:

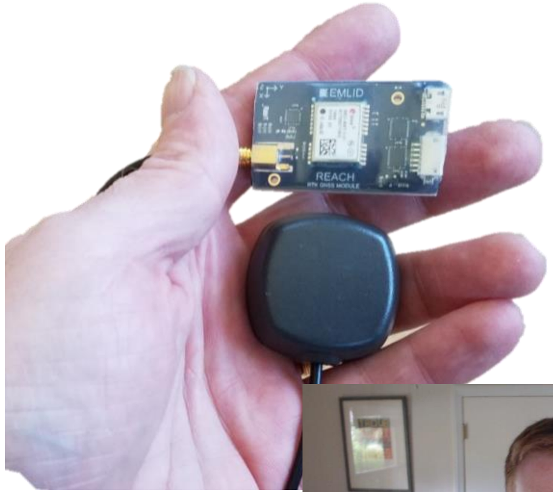
tpingel@vt.edu

tpingel.org



The Problem

- The coastal edge of the YP is exceptionally flat, confounding typical commercial-grade GPS units.
- New RTK GPS units are compact and inexpensive, and Unmanned Aerial Vehicles (UAVs) are increasingly small and are easier to operate than ever.
- **Can we use these small, commercial-grade RTK GPS units and UAVs to measure ground and water elevations within an acceptable error tolerance (< 25 cm)?**



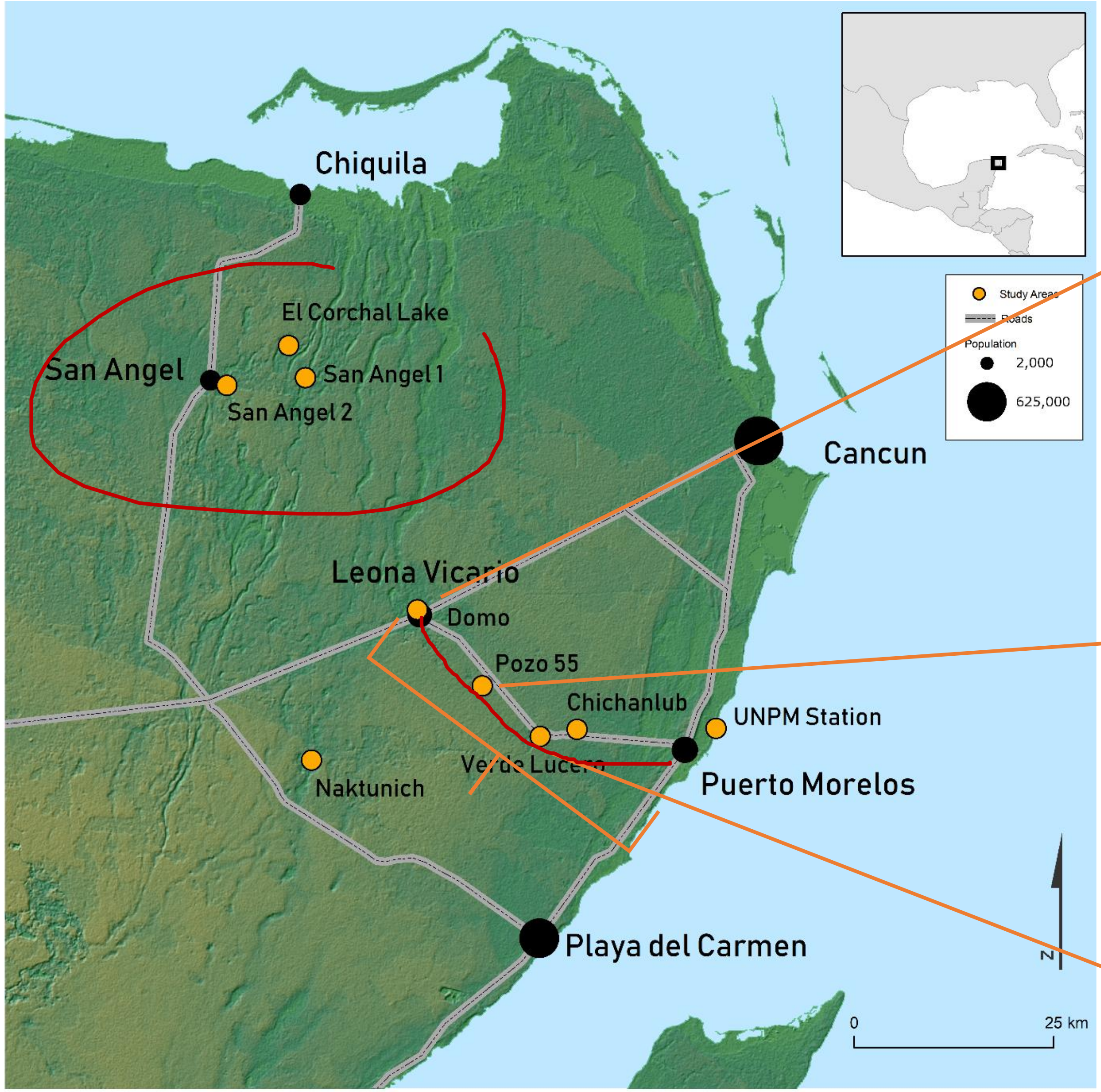
Our Component: Groundwater Elevation Models

- **We partnered with the geophysics team to develop more accurate land and water surface models at our study sites.**

- Geophysics team led by Phil Carpenter (NIU) and Jorge Perera (CICY) and included student researcher Aimee Garcia.

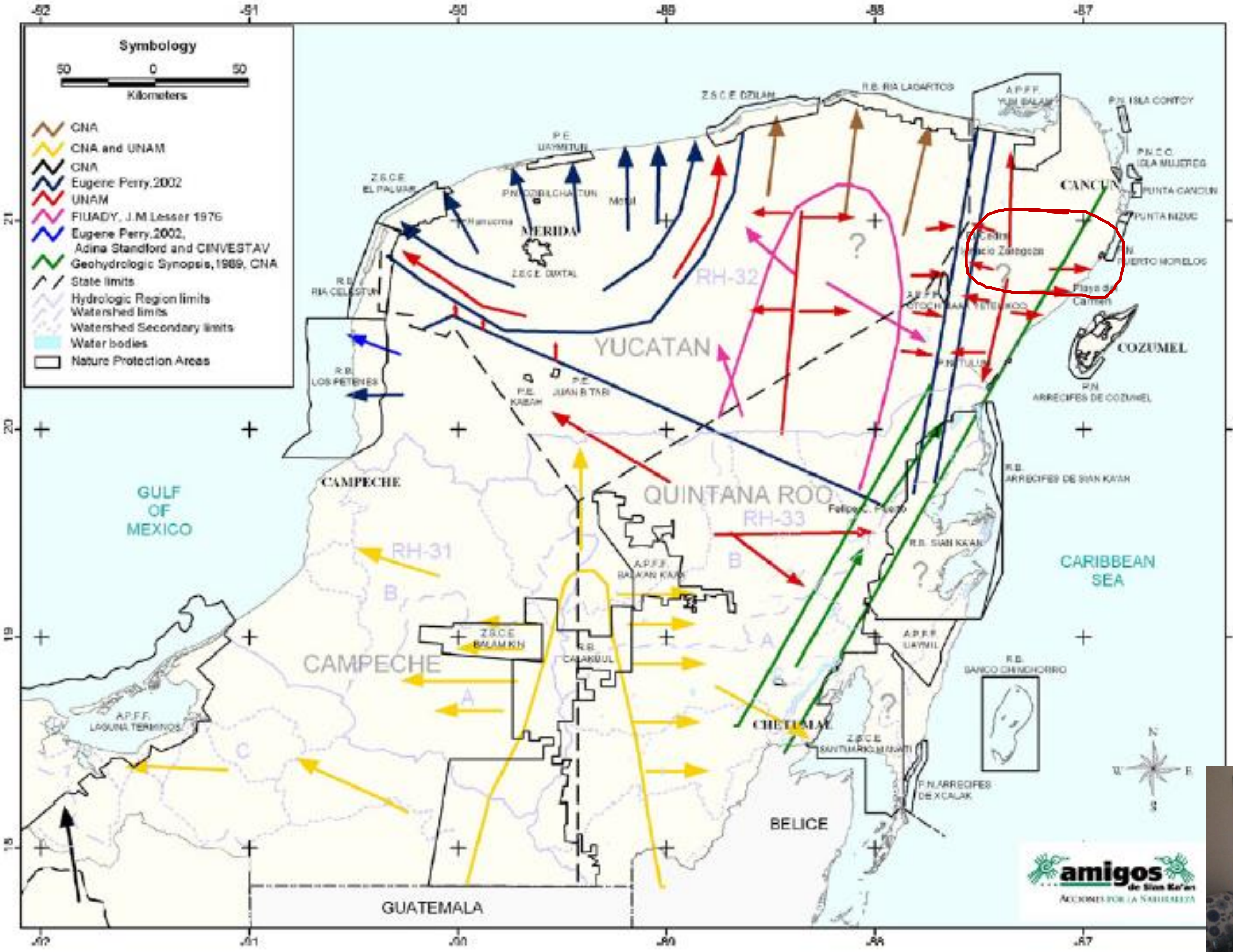
- Geophysics team used **ground penetrating radar and other instruments to measure water table depth** and location of freshwater-saline boundary delineate karst conduits.

- **Our task was to map surface elevations and measure exposed surface water (where present) to tether their depths to real world coordinates.**


Chiquila
El Corchal Lake
San Angel
San Angel 1
San Angel 2
Cancun
Leona Vicario
Domo
Pozo 55
Chichanlub
UNPM Station
Verde Lucero
Naktunich
Puerto Morelos
Playa del Carmen
Study Areas
Roads
Population
2,000
625,000
0
25 km
N

Site	Description
Chichanlub (20.8680, -87.0248)	Deep recreational cenote used for scuba diving along la Ruta de los Cenotes.
El Corchal Lake (21.2720, -87.3495)	Area with surface water, occasionally utilized for eco-tourism.
Leona Vicario (20.9938, -87.2043)	Non-recreational cenote located in Leona Vicario.
Naktunich (20.8356, -87.3237)	Large cenote recently developed for recreation and tourism, not yet open to the public.
San Ángel A (21.2379, -87.3306)	Surface water located in a fracture zone near the town of San Ángel.
San Ángel B (21.2300, -87.4192)	Surface water located in a fracture zone near the town of San Ángel.
UNPM Station (20.8658, -86.8682)	Marine research station located near the coastal city of Puerto Morelos.
Verde Lucero (20.8606, -87.0660)	Popular tourist cenote used for swimming along la Ruta de los Cenotes.
Well Field (20.9268, -87.1314)	Road with wells used for Cancún water supply, located along la Ruta de los Cenotes.

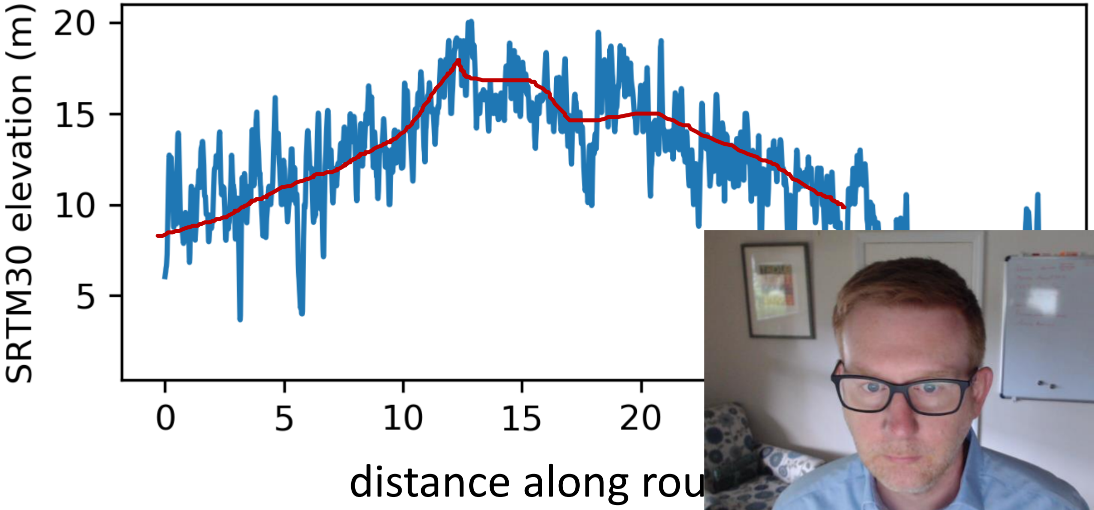
Table 1. Description of study sites.



Consensus map of groundwater flow. Image from Bauer-Gottwein et al. (2011).

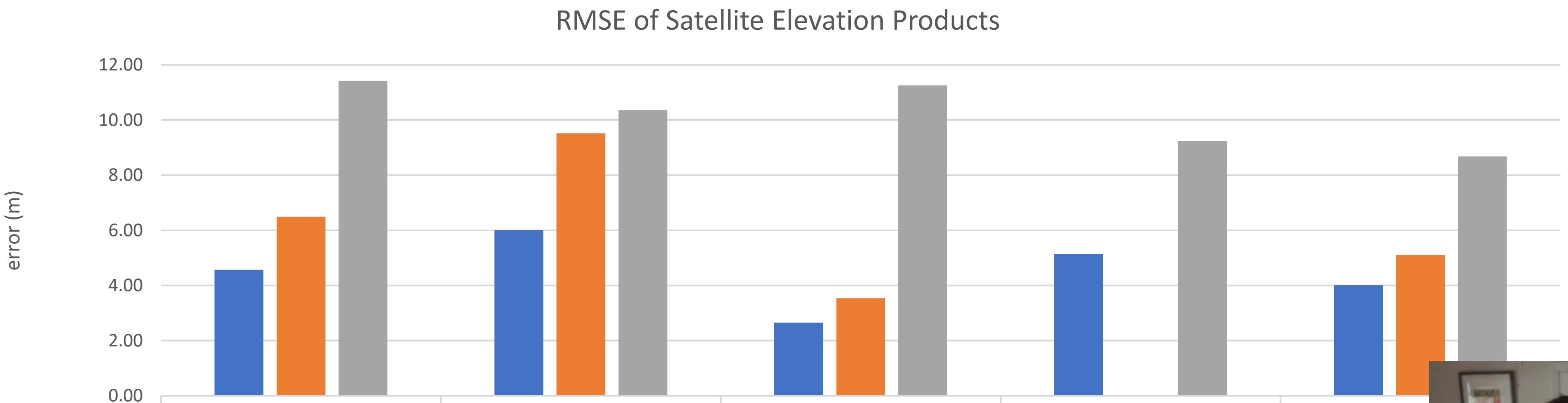
From Leona Vicario (NW) to the end of the Ruta de Cenotes in Puerto Morelos (SE) there is a total elevation change of ~17 meters.

The profile (~1000x VE) tracks both the variability in terrain as well as the noise / error inherent in the SRTM 30 data that makes it too unreliable for direct use, although smoothed products may be of value.



Satellite elevation estimates for Mexico (left) and the study area (center) are commensurate with the CONUS values reported by Gesch et al. (2011).

Errors are known to be slightly greater in forested environments.



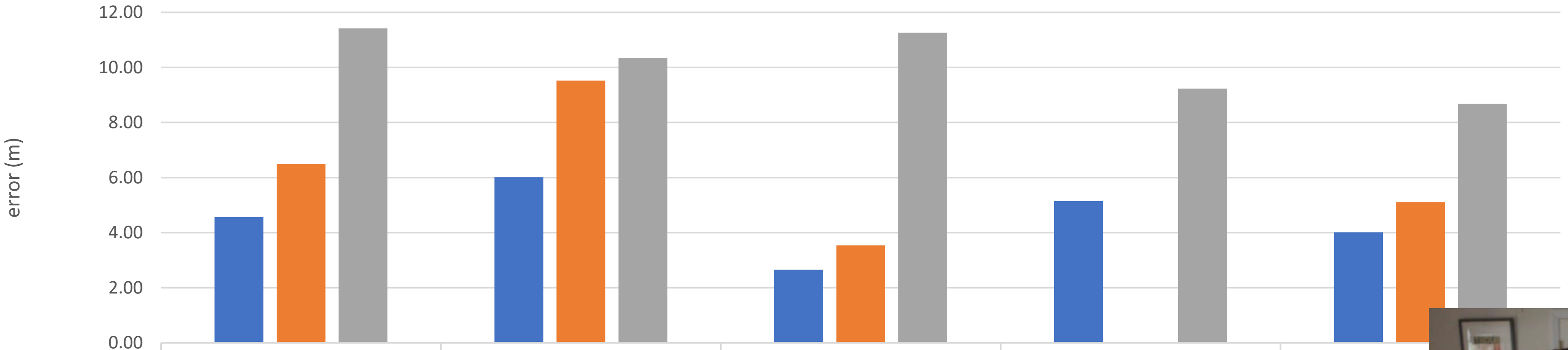
	Mexico (Active, n=30)	Mexico (Passive, n=4,743)	Yucatan (n=792)	CONUS (Forested)	CONUS (Gesch
SRTM (30 m)	4.57	6.01	2.65	5.14	4.0
SRTM (90 m)	6.49	9.52	3.54		5.1
ASTER GDEM22	11.42	10.35	11.26	9.23	8.6

Statistics for Mexico calculated by first author with benchmark data provided by INEGI.

Median absolute error for SRTM30 in the study area is 1.41 meters.

(95^{th} percentile 5.58 meters)

RMSE of Satellite Elevation Products



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Differential & Real Time Kinematic GPS Measurement

Because of the relatively large error relative to absolute elevation difference inherent in the satellite elevation data, researchers have turned to direct measurement using total stations and DGPS to measure spot heights in the Yucatán (Marín et al., 2008; Gondwe et al., 2010).

Marín and Gondwe reported mean absolute errors of ~ 4 cm for dual-band DGPS devices given 3 hours of recording time.

Newer RTK GPS units use similar methods, but are substantially less expensive; this makes the technology much more readily deployable.

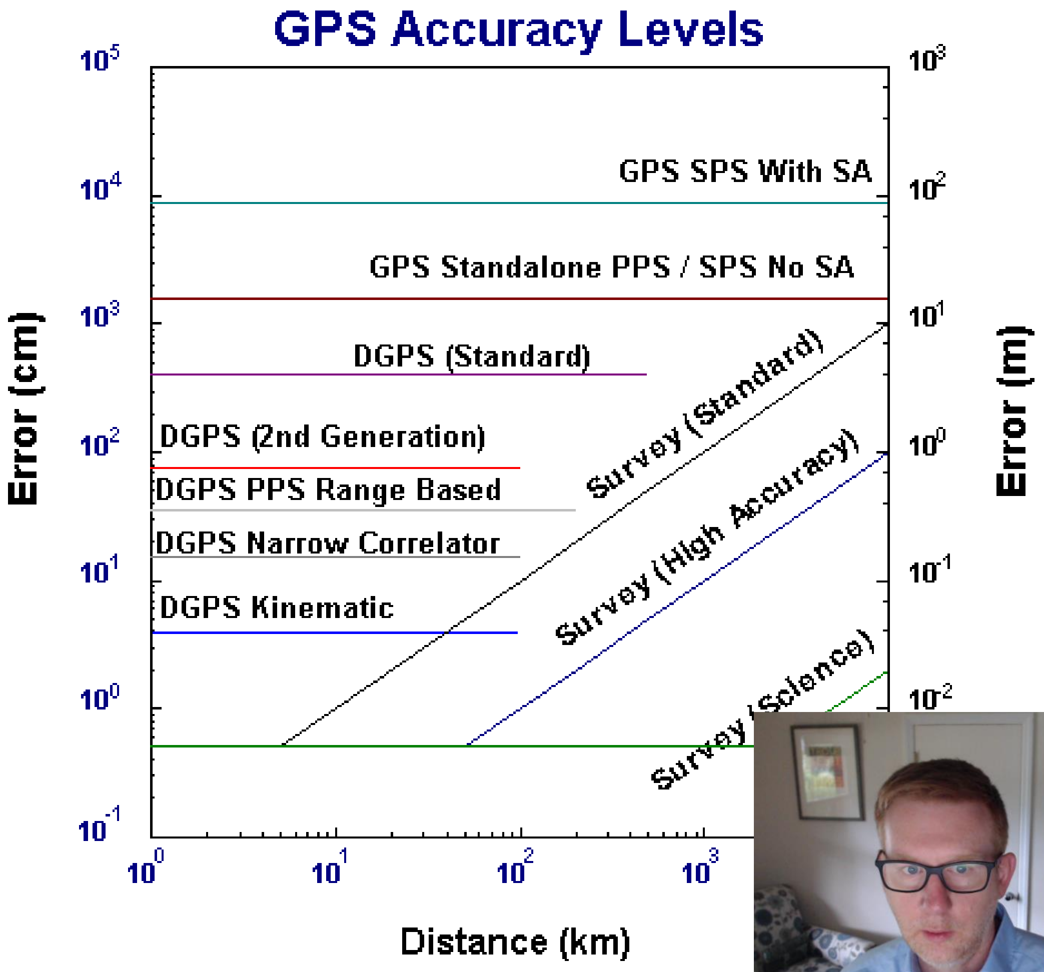
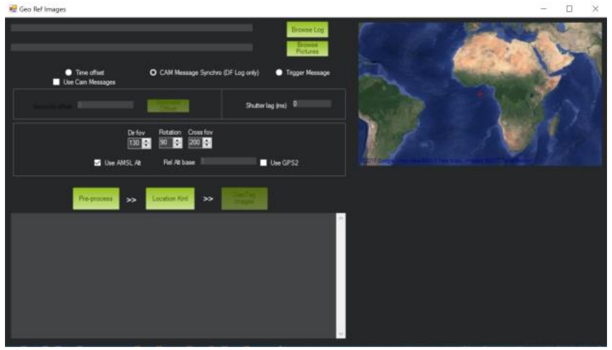


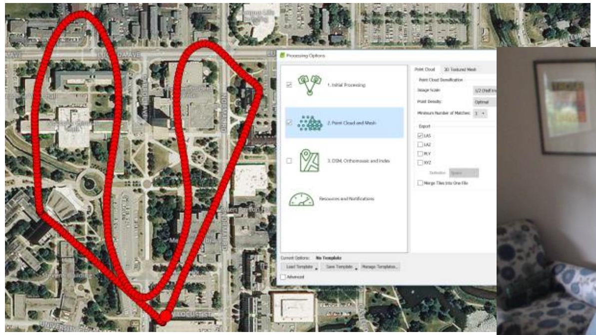
Image from Naval Postgraduate School.

Materials (UAVs)

- 3DR Iris+ and custom designed, 3D printable mapping drone based on Pixhawk2 (“The Cube”) flight controller.
- GoPro Hero 4 Black (12 MP) mounted to collect at nadir. Image rate adjusted for altitude flown (1-4 sec).
- Missions planned with Tower (now Mission Maker for ArduPilot) on-site.
- Generally flew 2-4 missions per site, for double-grid coverage, multiple elevations, 90% overlap, 85% sidelap.
- Images were geotagged in Mission Planner using drone GPS
- Sites reconstructed with Pix4D using Map template (optimized)






Materials (RTK GPS)

- Emlid Reach ($265)
- Corrections transmitted via Bluetooth, wifi
- Newer models capable of transmitting via LoRa radio
- Post-processing available
- Reported accuracy of ~ 5 cm
- Use case generally involves transmitting corrections to from “base” to “rover” (e.g., a drone) in real time or post-processing the data.
- **Unless absolute position of base is known (or calculable), corrections are only relative.**

Home › Type › Sensors › Emlid Reach RS2 Multi-band RTK GNSS receiver $1899

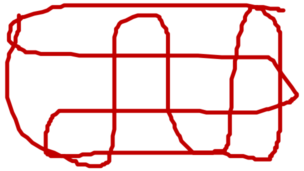
Featured Sensors

Emlid Reach RS2 Multi-band RTK GNSS receiver $1899

By **Press** - 25 March 2019

Emlid, the creators of Reach, centimeter-accurate RTK GNSS receiver, launched pre-orders for their multi-band GNSS receiver Reach RS2. The new receiver features built-in LoRa radio, 3.5G modem and a survey app for iOS and Android.

On Site Workflow

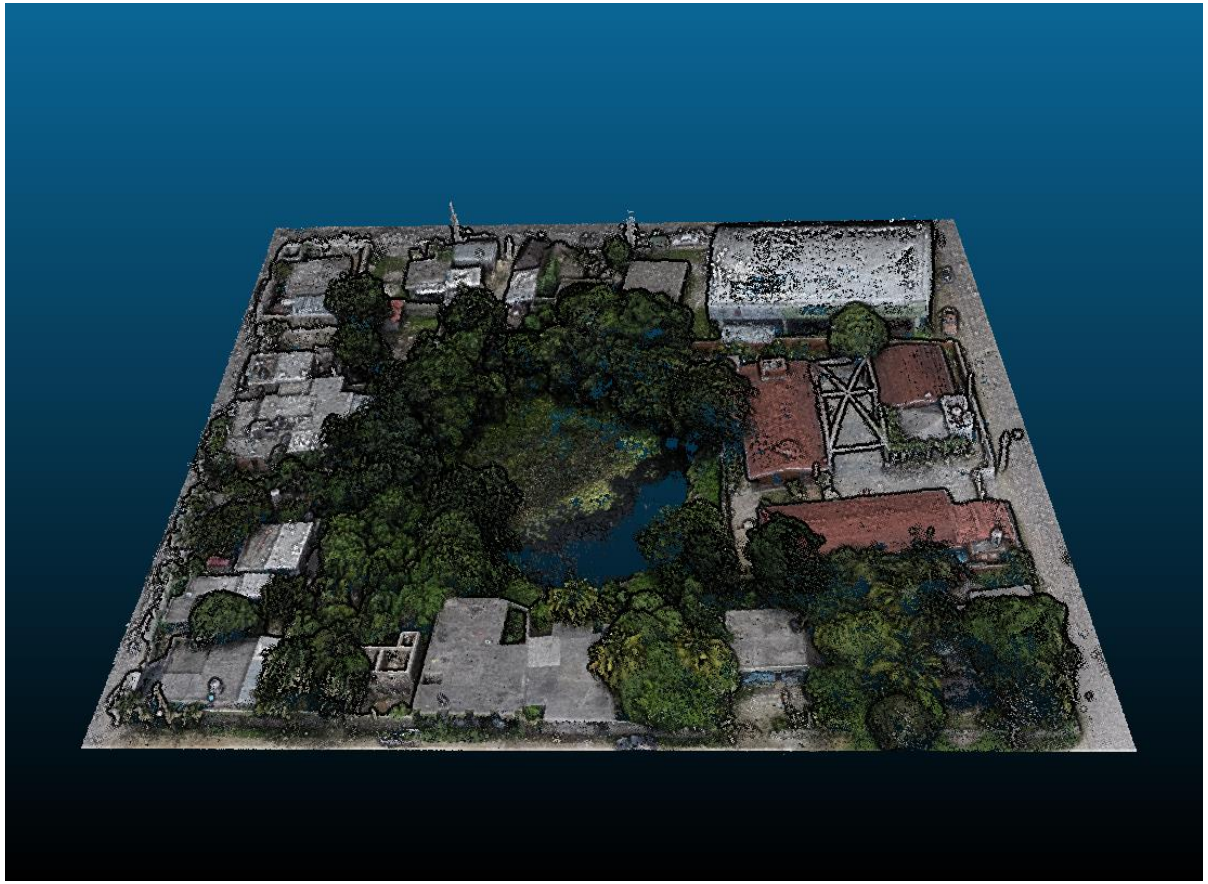


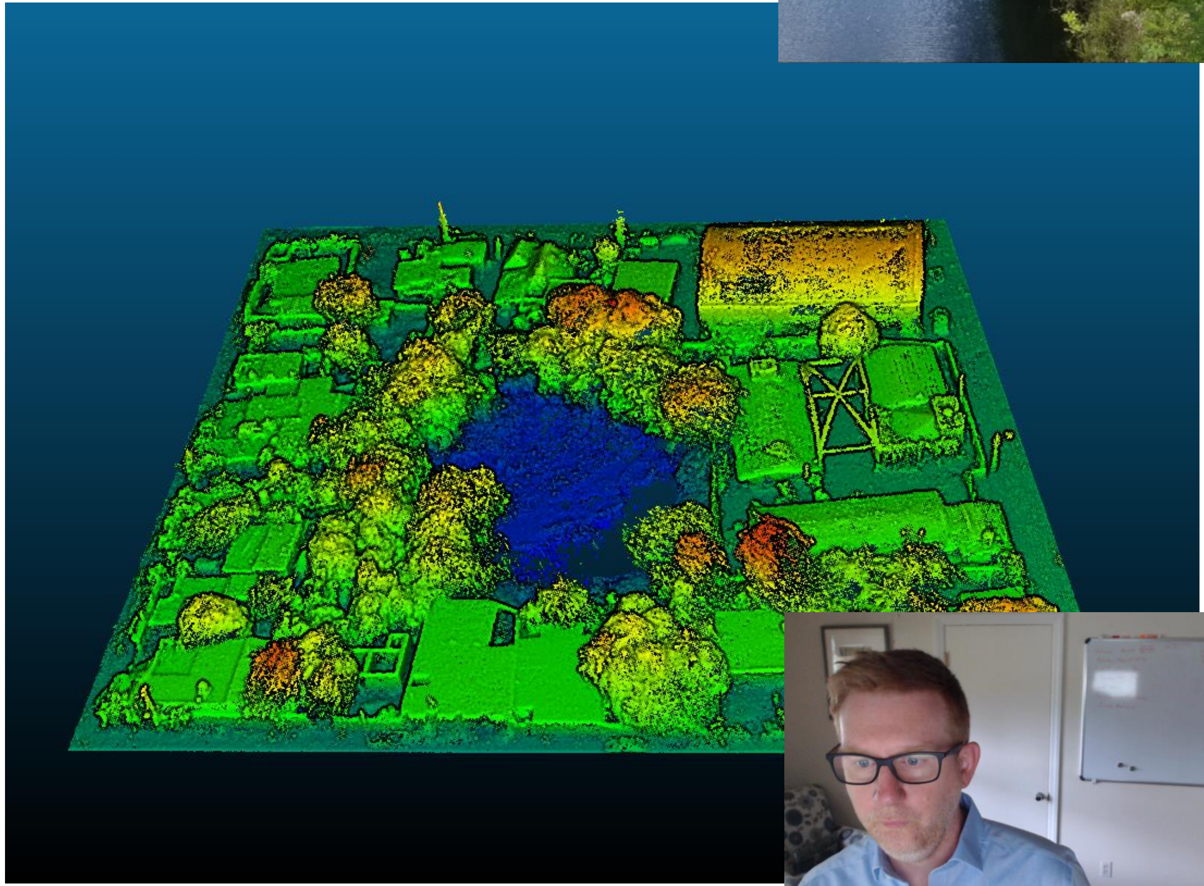
- Set up 2 RTK GPS units to continuously log coordinates while missions were flown (and water samples taken, etc., by other REU units). Units placed on colored cloth to make them easily seen in photos and reconstructions.
- In a few cases we were able to place GPS units directly on water surface to see if direct observation was possible
- Make flights using double-grids and at different elevations.
- Return to base for post-processing in Pix4D
  - Mean output point density ~250 rpsm
- **RTK GPS not used as GCPs in Pix4D, but post-reconstruction to recenter the point cloud.**

Mission	# Flights	Flight Altitudes (m)	Images	Area (hectares)	Points	Density (rpsm)
Chichanlub	1	60, manual	275	2.0	13,711,777	672.4
Leona Vicario 1	4	30, 30, 120, 20	1,328	2.6	3,812,564	144.2
Leona Vicario 2 (3)	1	30	272	2.6	34,045,107	1,304.4
Naktunich	1	120	672	147.0	5,322,315	24.9
San Angel A	1	30	576	0.4	10,846,651	2,543.8
San Angel B	1	30	407	1.6	20,732,312	1,268.8
UNPM 1	1	60	832	7.1	29,694,040	413.7
UNPM 2	1	60	191	5.1	13,403,027	259.3
Verde Lucero 1	4	60, 60, 30, 22	1022	2.6	16,104,225	607.8
Verde Lucero 2 (3)	1	60	219	2.6	16,762,450	633.1
Well Field 1	4	120, 120, 120, 120	693	67.0	73,925,663	110.4
Well Field 2 (3)	3	120, 120, 120	310	73.1	40,124,663	65.8
Well Field 3 (4)	1	120	181	31.8	24,552,411	77.2

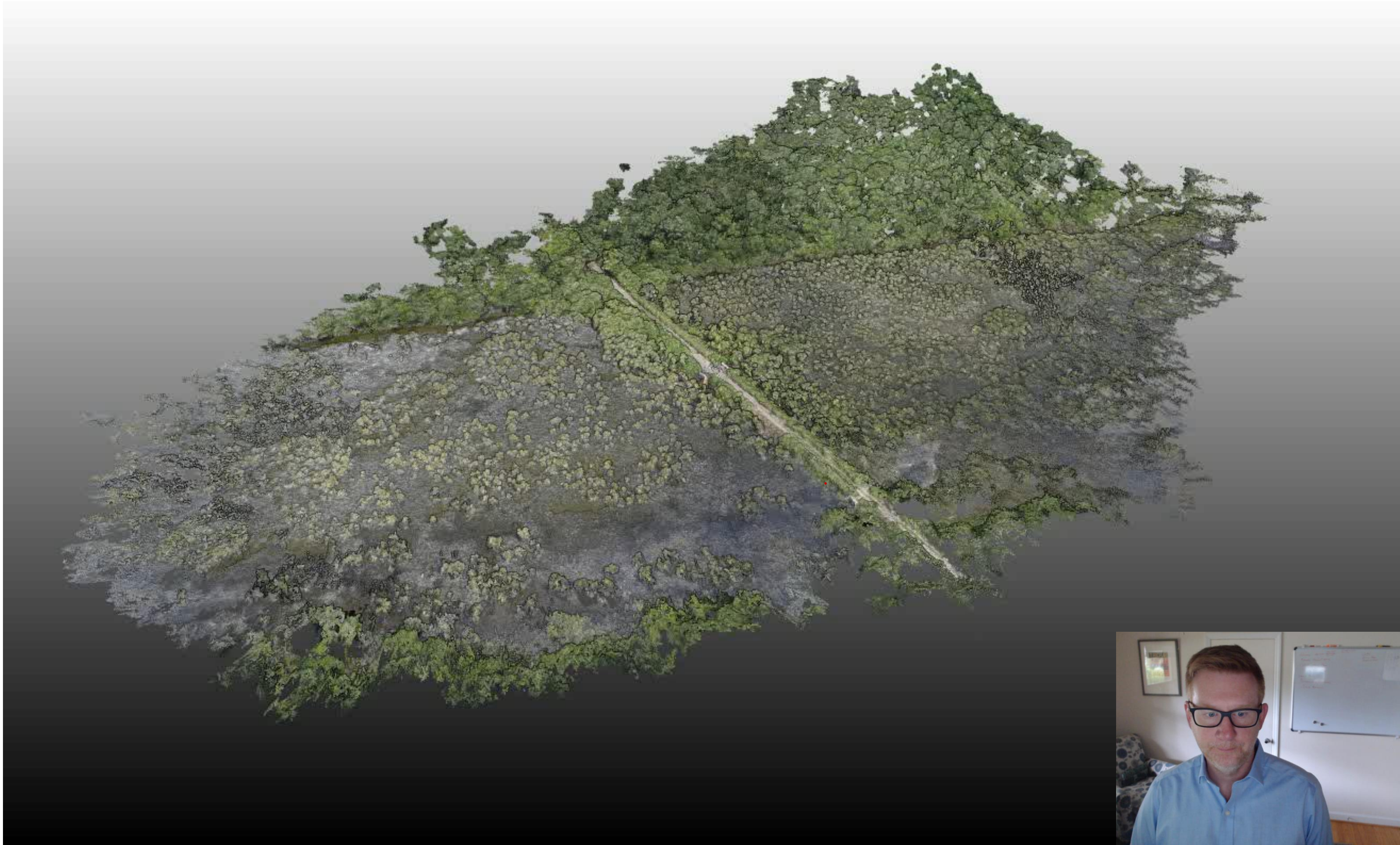
Table 2. UAV missions and resulting point cloud characteristics.

Leona Vicario



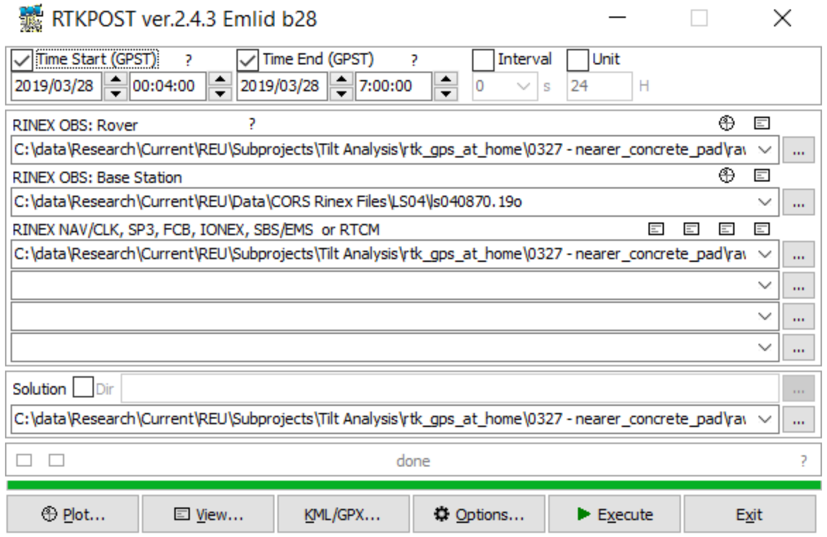


San Angel A

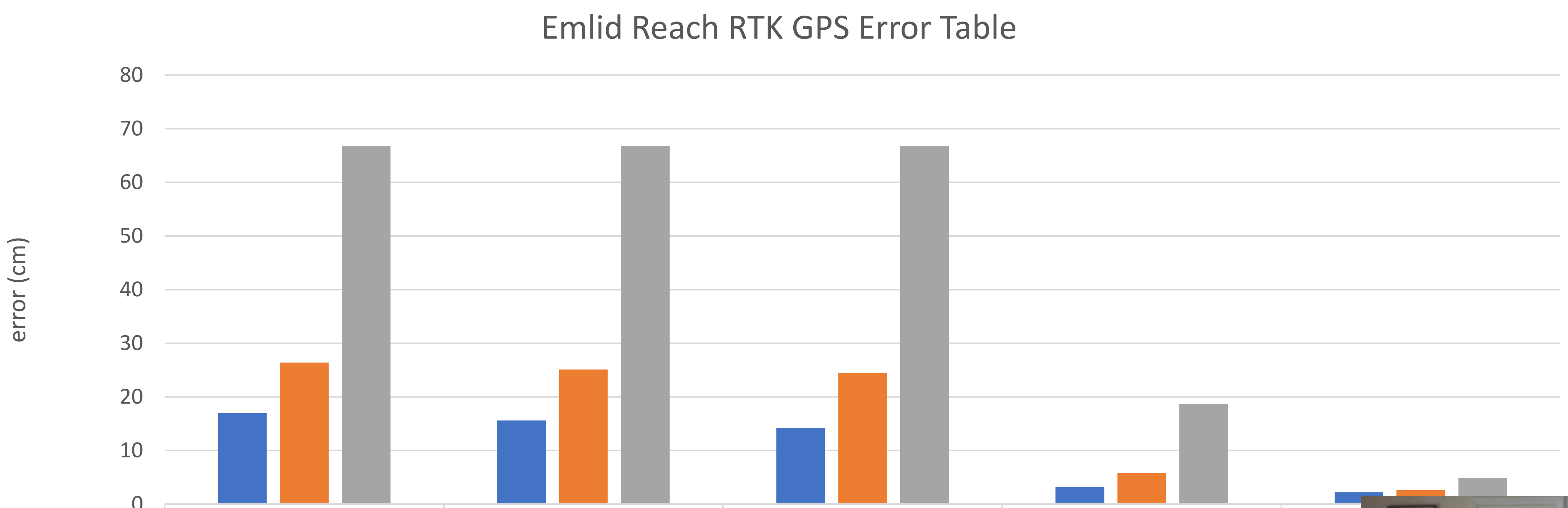


Post-processing RTK GPS Data

- We used a nearby CORS station (in Puerto Morelos) to provide correction data
    - A single static RTK GPS unit can be used to fill this role if a CORS station is unavailable
- Used RTKPOST to process the data
- This is a non-trivial step, and many of the methods here can produce fairly different results.
- We used guidance from Emlid, but tested how noise and altitude filtering, and integer ambiguity resolution settings affected the final result.
- Total of 40 GPS logs, mean obs time was 57.3 min



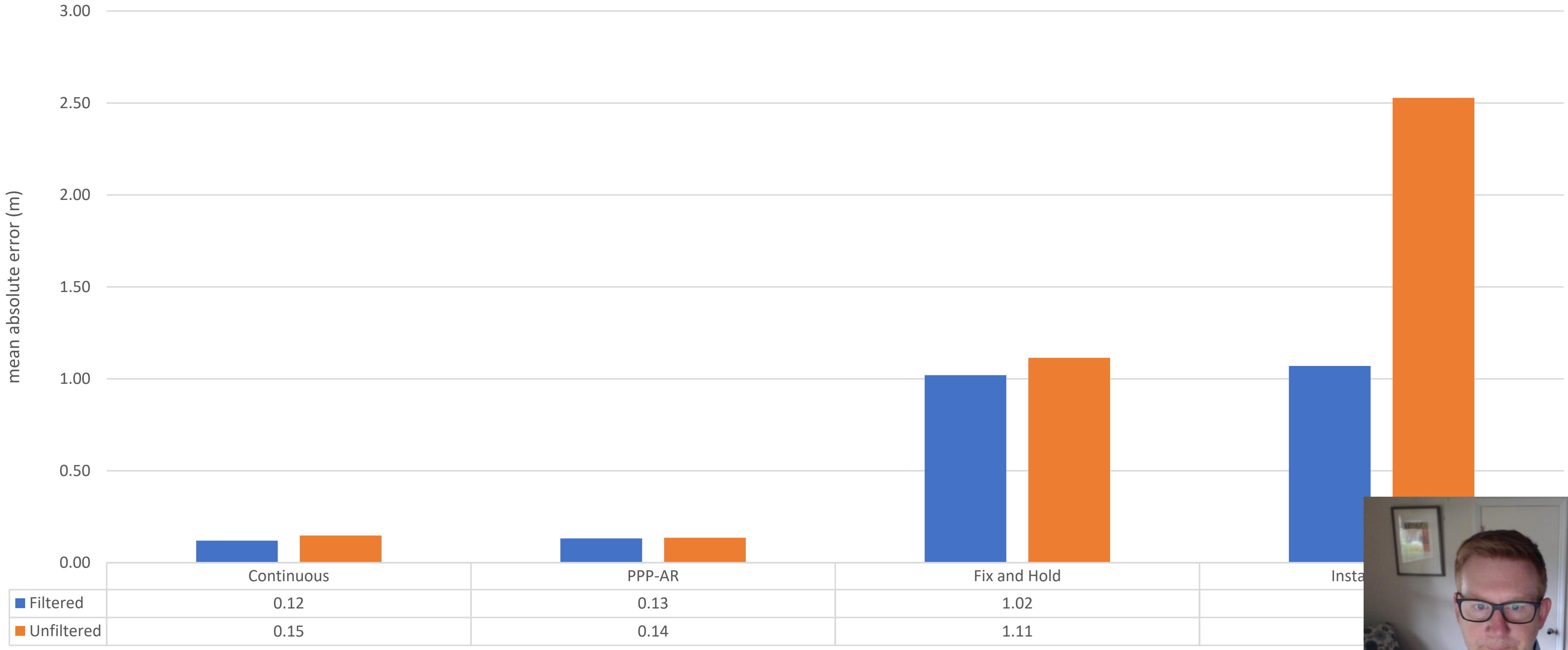
The accuracy of RTK GPS depends greatly on the length of observation time.



	15 minutes	30 minutes	1 hour	2 hours
abs mean err	17	15.6	14.2	3.2
SD	26.4	25.1	24.5	5.8
max error	66.8	66.8	66.8	18.7

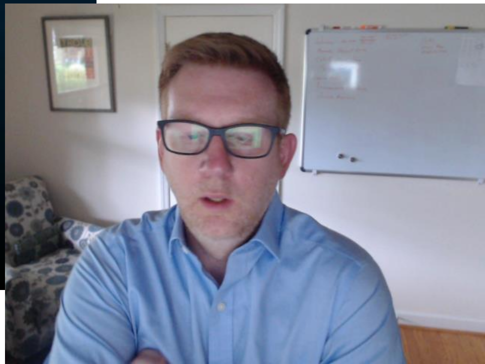
RTK errors by collection time (compared to 14 hour log)

The method of integer ambiguity resolution is quite important.

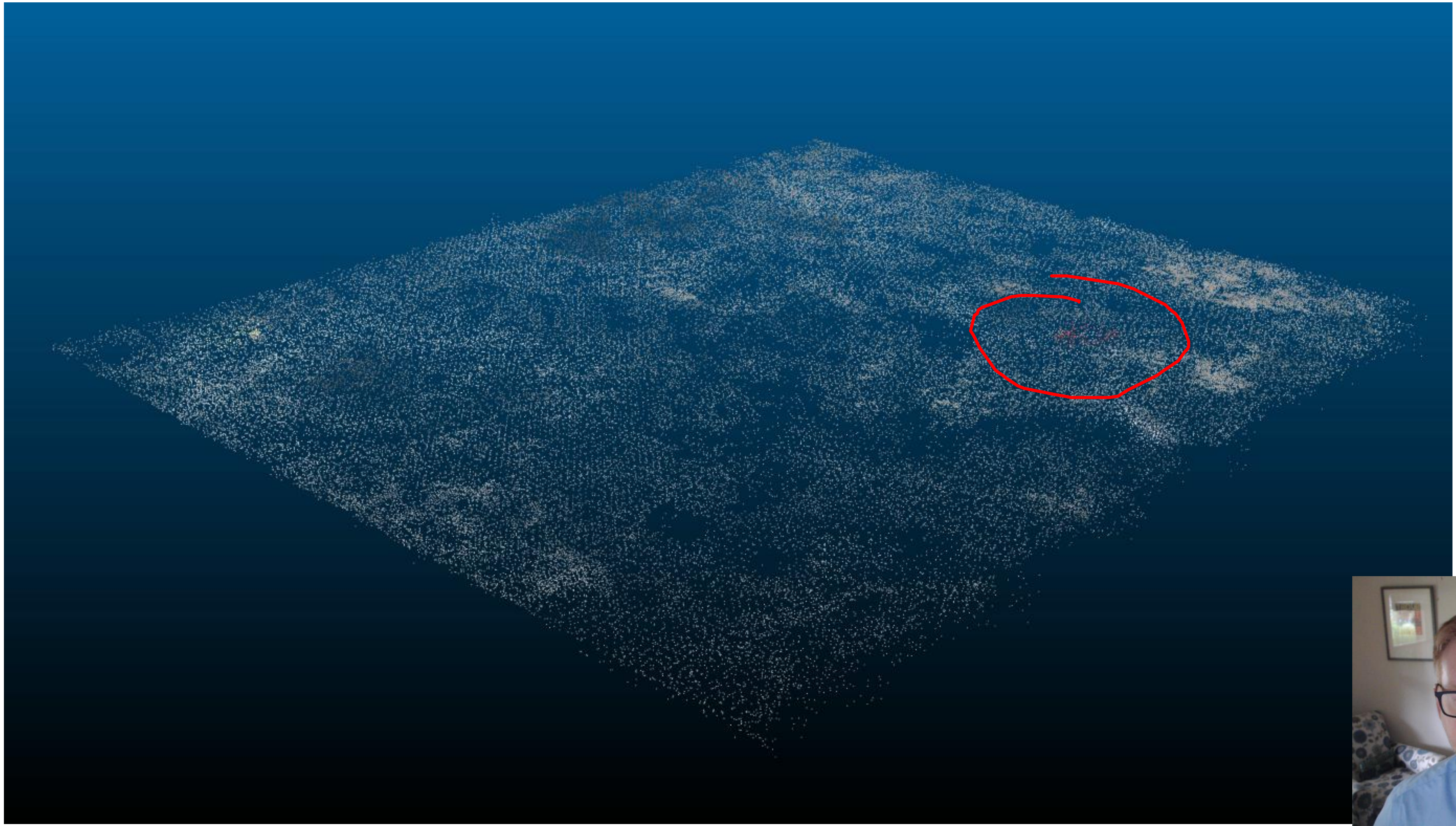


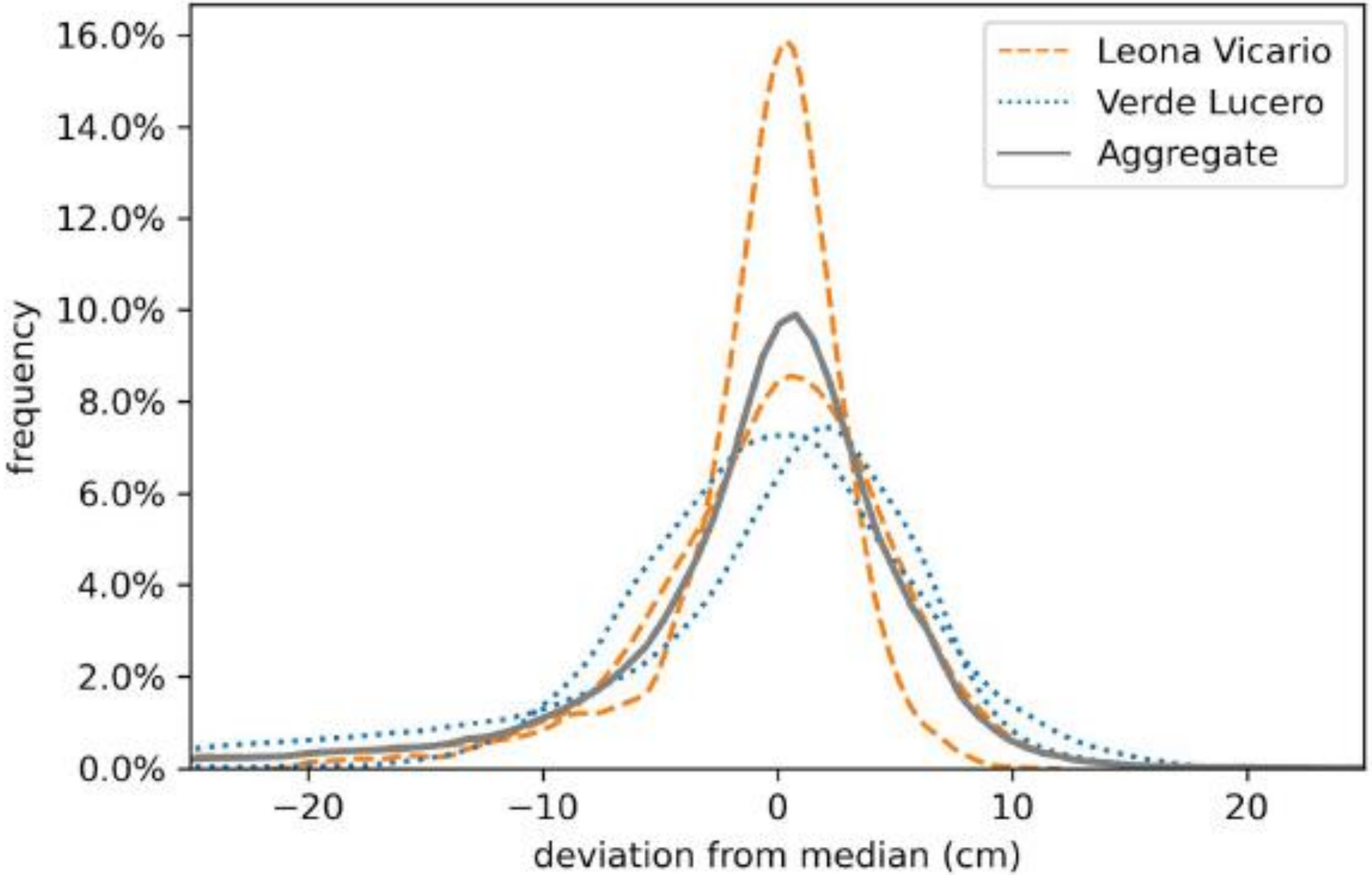
The point clouds contain substantial noise

Water can be particularly difficult to reconstruct, but is easier when there is vegetation.



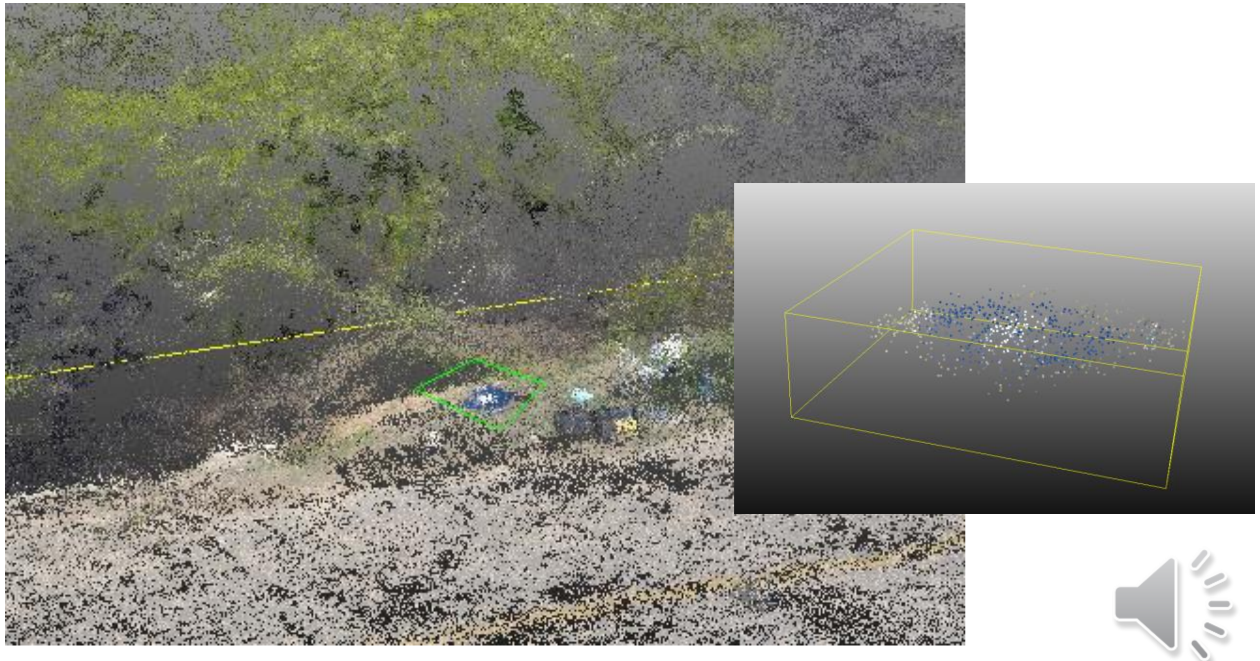
In several places, flat objects (rooftops, building foundations) allowed us to clearly inspect the thickness of the resulting point cloud.

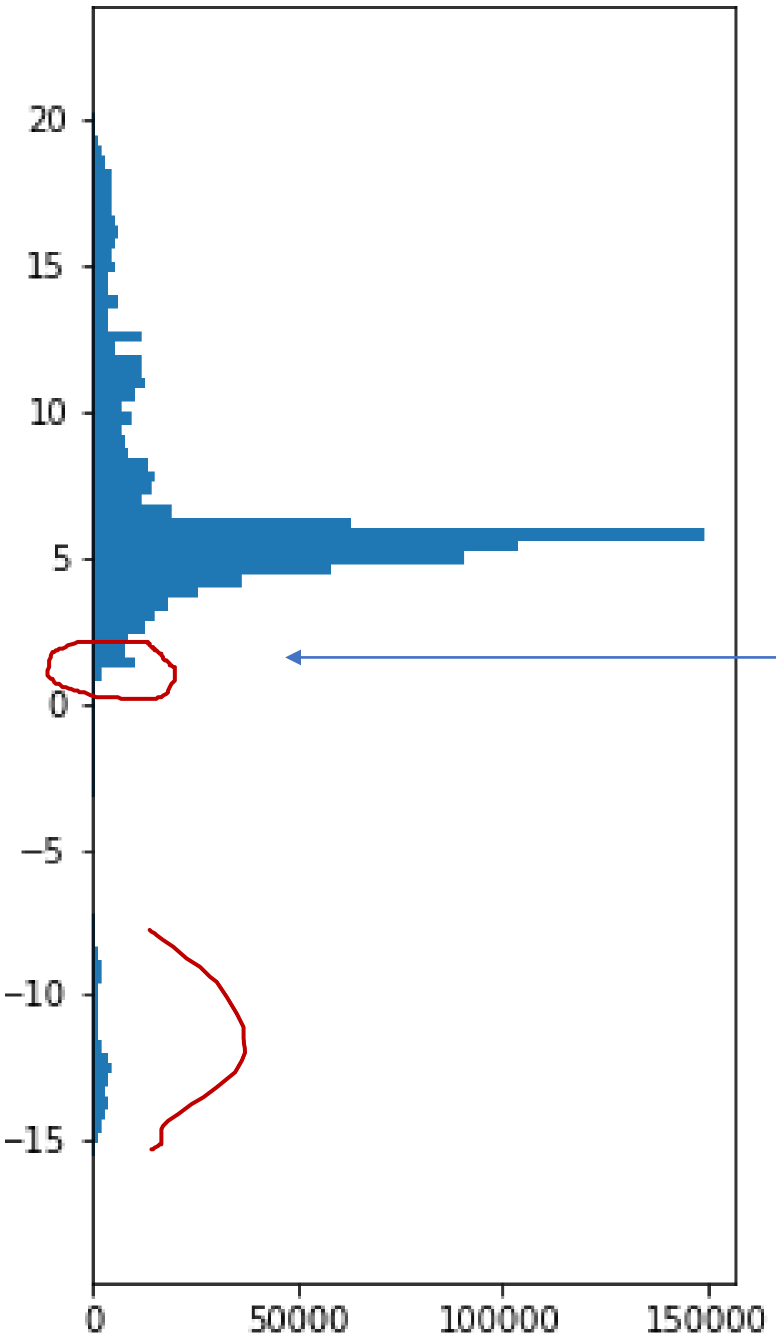



Leona Vicario
Verde Lucero
Aggregate
16.0%
14.0%
12.0%
10.0%
8.0%
6.0%
4.0%
2.0%
0.0%
frequency
−20
−10
0
10
20
deviation from median (cm)

Cloud registration method

- Load point cloud, isolate location where GPS was (e.g., rooftop)
- The difference between RTK GPS and median position shows the error in the drone GPS
- I correct for this, and then measure the water height in the point cloud
- I can compare this height to the “boat GPS” – a direct (but also flawed) measurement of water height



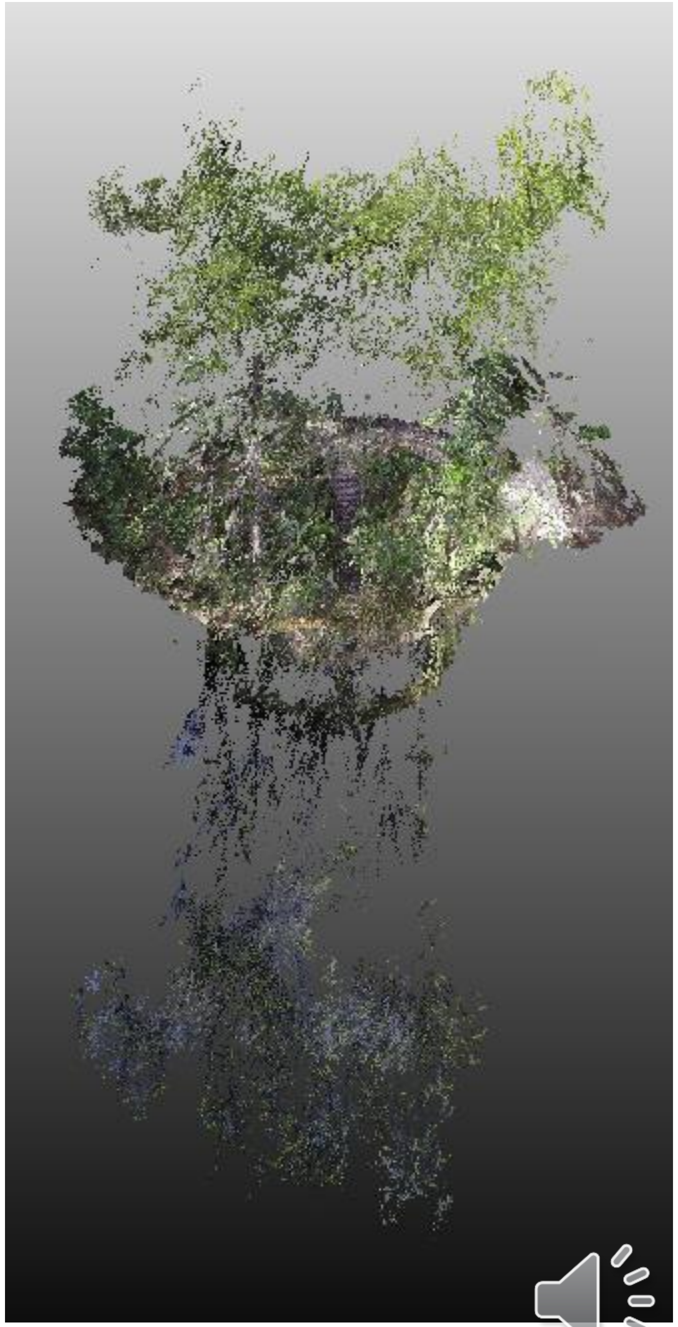


Leaves and branches

Land surface / cenote rim

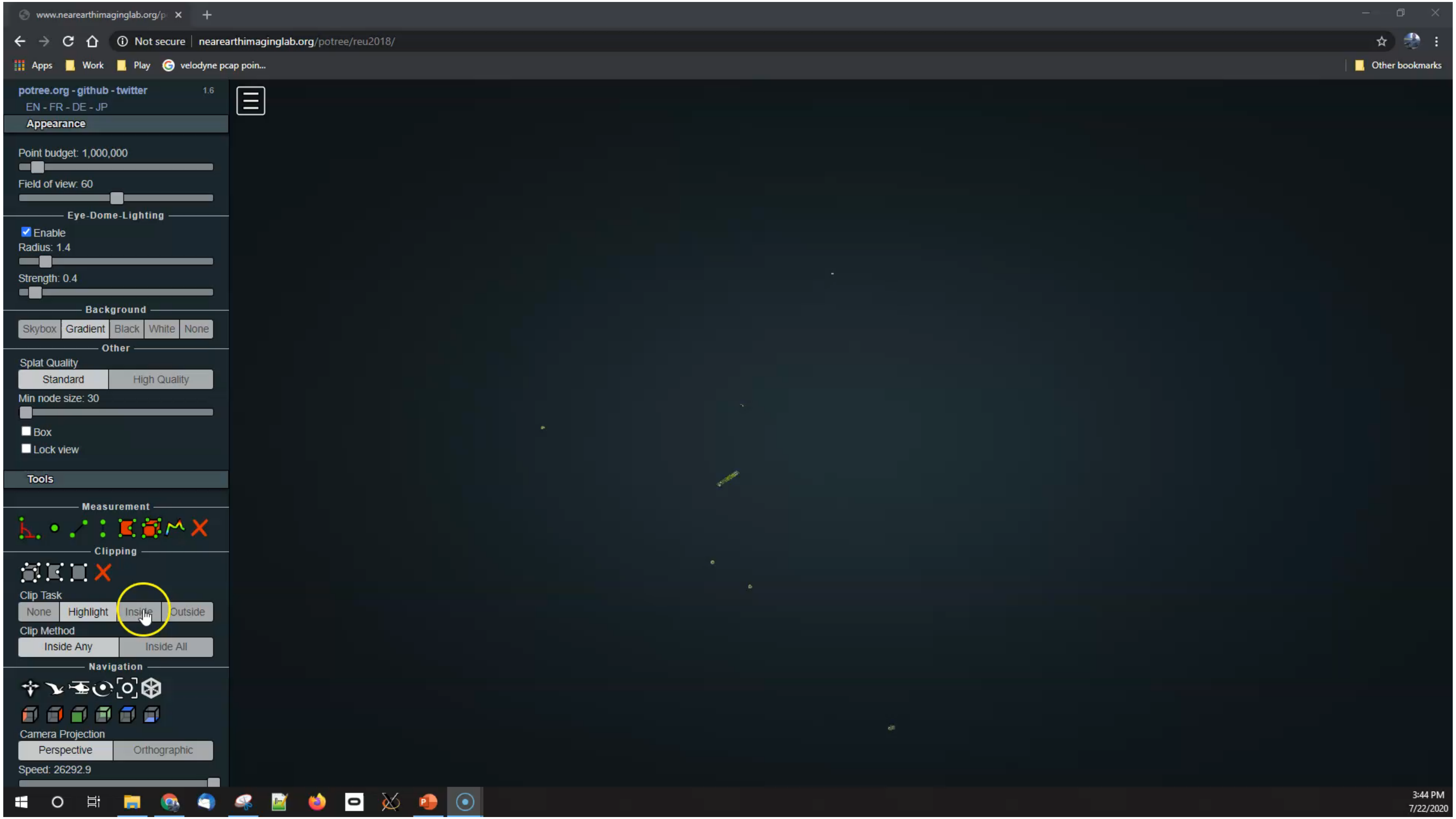
Debris on surface of water

Reflections rendered as depth objects



Site	WSE (m / EGM96)
Chichanlub	1.61
Leona Vicario	2.52
Naktunich	2.18
San Angel A	2.83
San Angel B	-
Verde Lucero	2.61
Well Field*	1.66

Table 3. Final Water Surface Elevation (WSE) estimates for non-coastal sites. Well Field includes a secondary estimate of water table.



http://www.nearearthimaginglab.org/potree/reu2018/

Conclusions

- **Our aim was to investigate the feasibility of this method. Can it be used to generate DEMs and water surface measurements within our error tolerance?**
- <u>There are more accurate ways to do this, but they are more expensive.</u>

1. The error in satellite-based elevation observations is too great for them to be used directly in the Yucatán for this purpose.
2. When static post-processing RTK GPS data, continuous and PPP-AR methods outperform instantaneous and fix-and-hold methods.
3. Keeping the RTK GPS in place for at least two hours is critical to reducing error.
4. Flying larger areas reduces tilt in the photogrammetric point cloud; when flying a corridor, flying a sawtooth pattern helps to reduce tilt.
5. Assuming distance-to-target is relatively short (~50-100 meters), a single RT
be used to anchor a point cloud to absolute coordinates within a 25 cm tole